Development of Information Theoretic Measure -Based Algorithm for Image Processing

SHORT SYNOPSIS

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By

Romisha

Registration No.-MRUECDN012K180559

Under the supervision of

Prof. (Dr.) Shruti Vashist

Dean Academics & Professor

Department of Electronics and Communication Engineering

School of Engineering

MANAV RACHNA UNIVERSITY

Sector-43, Aravali Hills, Faridabad

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Date: 2nd Feb, 2023

DECLARATION BY THE SCHOLAR

I hereby declare that the short synopsis entitled '**Development of Information Theoretic Measure-based Algorithm for Image Processing**' being submitted in partial fulfillment of the requirement for the degree of Doctor of Philosophy in the Department of Electronics and Communication Engineering under the School of Engineering of Manav Rachna University, Faridabad during the academic year 2022-23.

It is the work that is expected to be carried out under the supervision of **Dr. Shruti Vashist,** Dean Academics & Professor, Department of Electronics & Communication Engineering, MRU.

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Kanishka

Registration No.: MRUECDN012K180559

MANAV RACHNA UNIVERSITY

MANAV RACHNA UNIVERSITY

Sector-43, Aravali Hills, Faridabad

Date: 2nd Feb, 2023

CERTIFICATE BY SUPERVISOR(S)

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Prof. (Dr.) Shruti Vashist

Dean Academics & Professor

Department of Electronics & Communication Engineering, MRU

ABSTRACT

In the industrial world, the information required to make decisions about micro-objects, where small deviations can lead to failures, is of critical importance. Here, image sensing and processing play a crucial role, especially in situations where the direct analysis of data through human eyes is not feasible. Nonetheless, it aids in obtaining precise information by extracting visual data from any situation or object. As of now, in image processing, many alternatives are available related to data filtering, such as geometry-based feature extraction, etc. These filtering alternatives are impacted by the presence of noise and blurriness in images. Many researchers have proposed algorithms related to the extraction of data from images and getting precise information. The present work proposes the inclusion of fuzzy-based filtering methods in image sensing so that all such issues are well addressed. This is a non-linear method for processing the images that improves and segments the images by using information-theoretic methods. Further, the present work will also help in analyzing the behavior of various information-theoretic measures, extracting most of the key features of the images, and addressing the weaknesses in the existing image segmentation methods.

Keywords: Image Processing, Feature Extraction, Fuzzy Systems, Image Segmentation, Theoretic Measure-Based Algorithms

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1.0 Introduction

In the real-world situation, decisions can be only on the real-time facts and data available. The data is available in the form of quantitative and qualitative form. Images are also the source for raw data that can be converted into the information through various processing techniques. Though, it is the well-known fact about the images that many-a-time information gathered from the images are limited and imprecise in nature. For such scenario, prediction to any present or future outcome becomes difficult and the strong assumptions to take any decision.

In general, the image processing refers to a technique that is used for comprehensively extraction of information from the images. (Serra, 1982) In image processing, filtering is an essential component that involves estimation of noise. It is the well-known fact about the images that they are encountered with noise of different types which lead to difficulty in processing of information from the images. The removal of noise from the corrupt images becomes the essential task. (Friedman et al., 1989) Though, many linear processing techniques have already been proposed to filter the images but were not capable to eliminate the Gaussian noise from the images. (Due Trier et al., 1996) For this, the non-linear filtering techniques were also proposed to suppress Gaussian noise and preserve the edges (refining the images).

The uncertainty in the environment affects the decisions and leads to failure many-a-time. Such uncertainties become essential to handle carefully before the decision to avoid any conflict of interest among the all interested parties. To overcome such environments, the development of fuzzy based models helps a lot and increased the level of confidence of the decision makers. In the image processing, the fuzzy based filtering techniques were also introduced. These fuzzy based techniques have the capability to reasoning like human beings and reported as good for eliminating the noise from the images. (Bezdek, 1981; Bloch and Maitre, 1995) It is also evident that many techniques were proposed to remove noise in gray scale and color images. The most of the existing techniques were presented filters to resolve the issues with gray-scale of images. Even, these techniques were extended to resolve the issues to the color images limited to the certain features.

In the fuzzy models, the memberships in image processing quantifies the amount of vagueness/ambiguity. The appearance of fuzziness in images or in projections is manifold ranging from ambiguity in pixel based gray region in the processing of highest image level from their geometrical description to uncertain information. Moreover, the human visuals and

reasoning system configured to deal with uncertain information in terms of geometrical primitives such as shape, dimension and color. Descriptive language has been used to define features because of wide range of variations. This opens up the doors to the new discipline of fuzzy image processing that have the inbuilt capability to translate the reasoning of human vision into computer vision problems and provides an intuitive tool to draw inferences from imprecise data. The theory easily answers the common questions such as: How to define the boundary of the blurred imaged? Which values of the gray regions belongs to class of bright or dark pixels? How to define the transition region between a gray value slope and an edge? and many other questions of related types showed that image features should be considered a fuzzy. To classify images, thresholds have been assigned to the features to overrule such problems. Fuzzy image processing is a new image processing technique that provides new methodology to develop new type of image understating and treatment. It could be a single process or complement parts of complex processing chain.

1.1 Brief history of Fuzzy Sets in Image Processing

The concept of fuzzy sets over the classical set was developed by Zadeh in 1965. The fuzzy sets are also referred as the uncertain sets. These sets permit the assessment of elements membership valued in between 0 to 1. (Zadeh, 1965) These sets have the applications where the information available is vey less or imprecise. (Zadeh, 1973; 1975) More than five decades have been passed since the fuzzy set theory and its generalizations gained popularity in the field of image processing. In the initial stage, the fuzzy sets were applied in image processing through clustering method. (Ruspini, 1969) Later, the sets were specified by some membership function. (Prewitt, 1970) The first fuzzy clustering algorithm was introduced in 1971 which is the fuzzy 'C-Means' algorithm. (Bezdek, 1981)

The concept of topology and geometry of images to fuzzy sets was introduced which was the way forward to the development of mathematical framework of pattern recognition. (Rosenfield, 1979; 1984a; 1984b) Further, the new algorithms associated to fuzzy image processing work such as Histogram equalization (Pal and King, 1981); Fuzzy Skeletonization (Pal, 1989); Fuzzy Thresholding (Pal and Murthy, 1990); Entropy (Pal and Pal 1991); Fuzzy Geometry (Rosenfeld, 1984b; Pal and Ghosh, 1992) etc. were reported. These concepts provide the strength to the discipline of fuzzy image processing to grow. (Rosenfeld, 1990; Pal, 1994)

1.2 Fuzzy Set Theory

In the fuzzy systems, the prime components are the fuzzy sets. These sets are having the elements. These elements are further having memberships values. (Zadeh, 1965; 1972; 1975a). The preliminary requisitions for fuzzy sets are as follows:

A. **Crisp Sets:** Crisp set is a conventional bivalent set. For a crisp set A of X ,

$\exists$ $f_A(x): X \to \{0,1\}$; where, X is universal set.

and $f_A(x) = \begin{cases} 1, & if\ x \in A \\ 0, & if\ x \notin A \end{cases}$

In this set, element either is a member of set or not.

B. **Fuzzy Sets:** The classical sets' elements have degrees of membership, and fuzzy sets are an extension of such sets. (Zadeh, 1965) A discrete universe of conversation defines the fuzzy set *A*.

$X = \{x_1, x_2, ..., x_n\}$ as: $A = \{< x, \mu_A(x) > : x \in X\}$

Where, $\mu_A : X \to [0,1]$ is the membership function of set *A* and

$\mu_A(x)$ is called the grade of membership of $\mathrm{x} \in \mathrm{X}$ in A

Here, it is essential to point out that the selection of membership function based on shapes is the arbitrary and depends on the facts i.e.

a). Interested image features (which is the prime requisite), and

b). Fuzzy system desires.

Generally, the important membership functions are given piece-wise's in the form of polynomials of degree one and two (linear and quadratic) or trigonometric functions. In addition, to handle the complexity of fuzzy terms, various notations matched to fuzzy image processing were also developed. (Zadeh, 1975)

C. **Operations on fuzzy sets:** For fuzzy sets A, B, C and D in X , we have

[1] $A = B \quad iff \quad \mu_A(x) = \mu_B(x), \ \forall\, x \in X$

[2] $A \subseteq B \quad iff \quad \mu_A(x) \leq \mu_B(x), \ \forall\, x \in X$

[3] $B \supseteq A \quad iff \quad A \subseteq B$

[4] The union $A \cup B$ can be defined by one of the following membership functions as

[4.1] $C = A \cup B \quad iff \quad \mu_C(x) = \max\{\mu_A(x), \mu_B(x)\}, \forall\, x \in X$

[4.2] $C = A \cup B \quad iff \quad \mu_C(x) = \mu_A(x) + \mu_B(x) - \mu_A(x) \cdot \mu_B(x), \forall\, x \in X$ and

[4.3] $C = A \cup B \quad iff \quad \mu_C(x) = \min\{1, \mu_A(x), \mu_B(x)\}, \forall\, x \in X$

[5] The intersection $A \cap B$ can be defined by one of the following membership functions as:

[5.1] $D = A \cap B \quad iff \quad \mu_D(x) = \min\{\mu_A(x), \mu_B(x)\}, \forall\, x \in X$

[5.2] $D = A \cap B \quad iff \quad \mu_D(x) = \mu_A(x) \cdot \mu_B(x), \forall\, x \in X$

[5.3] $D = A \cap B \quad iff \quad \mu_D(x) = \max\{0, \mu_A(x) + \mu_B(x) - 1\}, \forall\, x \in X$

D. **Linguistic Variables:** The foremost feature of any fuzzy set is to translate the linguistic variable into fuzzy to reduce the complexity in describing the vague property of words or sentences. (Zadeh, 1973) Mathematically, The set of linguistic variables represented as X over the universe of discourse associated with the membership functions $\{\mu_{A_1}, \mu_{A_2}, ..., \mu_{A_N}\}$ that quantifies the variable 'x' by assigning a membership value to 'A_j'.

E. **Linguistic hedges:** In fuzzy systems, the linguistic variable are modified based on the shape of the image and its membership functions are also changed. The linguistic hedges are: Intensity modification (μ^i), Concentration (μ^c) and Dilation (μ^d) and are defined as:

$$\mu^i = \begin{Bmatrix} 2\mu^2(x), & \text{if } 0 \le \mu(x) \le 0.5 \\ 1-2[1-\mu(x)]^2, & \text{elsewhere} \end{Bmatrix}$$

$$\mu^c = \mu^2(x)$$

$$\mu^d = \sqrt{\mu(x)}$$

F. **Fuzzy Relations:** Let R and S be two fuzzy relations on $A \times B$ and $B \times C$ respectively. The standard composition of these relations is denoted by $R \circ S$, gives a binary relation $P(A, C)$ on $A \times C$ and estimated as follows:

$$P(A, C) = [R \circ S](a, c) = \max_{b \in B} \min [R(a, b), S(b, c)], \quad \forall\, a \in A, c \in C$$

G. **De-fuzzification:** In the image processing, the process of defuzzification has also its importance. It is the reverse process of fuzzification to assign the value $x \in X$ to the resulting output membership function. The most popular way for the defuzzification process is the computation of the mean of maxima of the corresponding membership function.

1.3 Fuzzy image processing

In the image processing, the uncertainty always seeks to be addressed on priority. The uncertainty occurs in an image because of the region under consideration (image boundaries), region nature (either homogeneous or heterogeneous), threshold level, noises and the background etc. (Pal, 1992; Li et al., 2019) This will cause the problems in the image processing ranging from low-level to high-level processing. The various effects of uncertainties are the extraction of imprecise information, complexity in class formation, noises during the process, concurring evidences etc.

Further, the problems such as digital geometry, mathematical morphology, statistical representation of the image etc. are of big concern to deal with. (Tizhoosh, 1997) The fuzzy systems and its generalizations can easily handle the complex and diverse problems of image processing. Fuzzy theory provides strong mathematical representation and expert knowledge for image processing. Fuzzy inference rules have been developed from expert knowledge that allows to perform actions. Figure-1 below reveals the presence on uncertainty at various stages of information extraction and issues pertaining to the images corresponds to these stages.

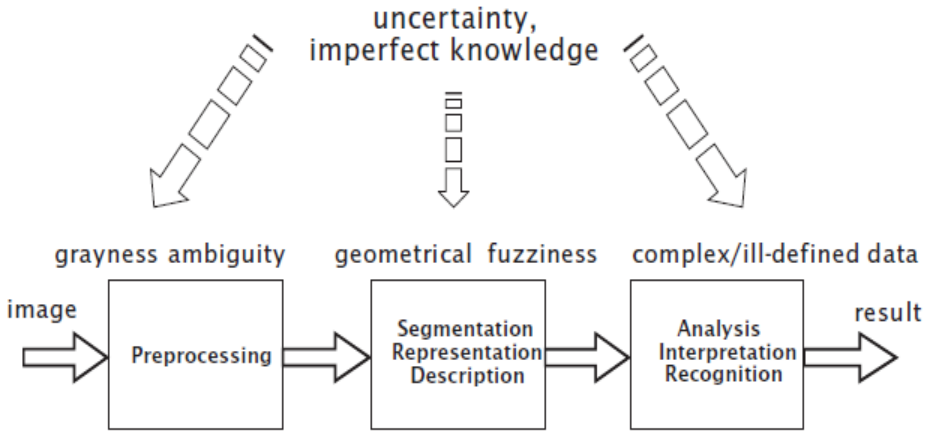

Figure (1): Imperfect knowledge in image processing (Tizhoosh, 1997)

Using fuzzy sets in the applications of image processing, the understanding of new image has been developed with the fuzzified version of image components such as: pixels, histograms, segments etc. and its transformation in membership plane. Moreover, fuzzy digital topology has been established.

A. **Define images as fuzzy sets:** For image properties (brightness, homogeneity, noisiness, edginess, etc.), image can be defined as in terms of membership value μ_{mn} of each image point x_{mn}.

   Mathematically, let G be an image with size $m \times n$ having L gray levels.

$$G = \bigcup_{i=1}^{m} \bigcup_{j=1}^{n} \frac{\mu_{ij}}{x_{ij}}$$

   The choice of membership values varies from application to application and on the corresponding expert knowledge. (Pal and Dutta, 1986; Tizhoosh, 1997)

B. **Fuzzification of Image:** Fuzzy version of image processing is a kind of nonlinear image processing as this technique operates on membership values. The first step in the processing of the image is the generation of suitable membership values (image fuzzification). The various types of image fuzzification is shown in figure 1a below:

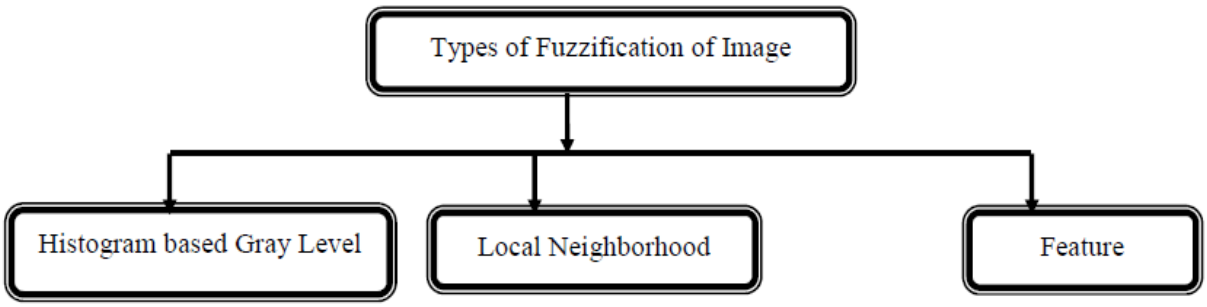

Figure (1a): In Image processing, types of fuzzification

Sometimes, fuzzification step is optimized to achieve better results in terms of number, form, and location of each membership function.

C. **Fuzzy Topology of an Image:** Segmentation of images is of important concern in extraction of precise information from the images. Fundamentally, while extraction of information, the regions of the image are defined through the fuzzy subsets. In the similar manner, the other topology facts such as of connected-ness, surrounded-ness and adjacency are also defined through fuzzy sets by using the thresholding technique of image segmentation.

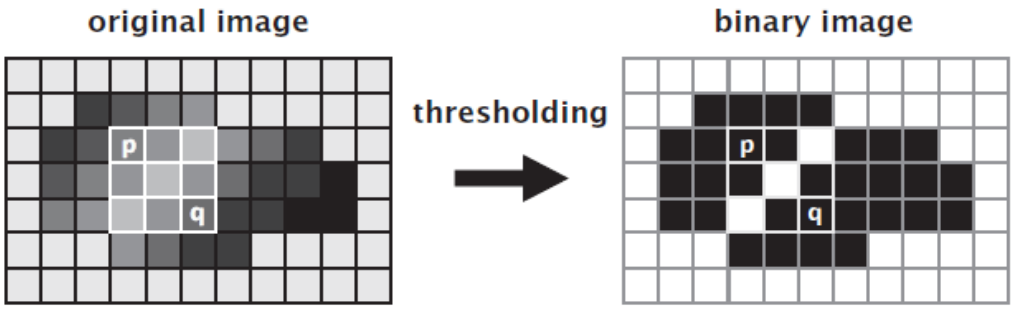

Figure-2: On crisp and fuzzy connectedness.

D. **Fuzzy connectedness:** Let $p, q \in U$, where *'U'* is the neighborhood of regions and μ be the membership function of modeling image *'U'*. The δ_{pq} be the paths from *'p'* and *'q'* containing the point r.

Figure (2) illustrates the definition of the degree of connectivity of 'p' and 'q' in 'U' with respect to the membership function (μ).

$$\text{connectedness}_{\mu}(p,q) \equiv \max_{\delta_{pq}}\left[\min_{r\in\delta_{pq}} \mu(r)\right]$$, if the following condition holds:

$$\text{connectedness}_{\mu}(p,q) \geq \min\left[\mu(p), \mu(q)\right]$$ (Rosenfeld, 1979)

E. **Fuzzy surroundedness:** Let μ_A, μ_B and μ_c be the membership functions of fuzzy subsets A, B and C respectively of image G.

The fuzzy subset C separates A from B, if $\forall\ p, r \in U(\subset G)$

All paths δ from p to q, $\exists r \in \delta$, if the following condition holds:

$$\mu_c(r) \geq \min\left[\mu_A(p), \mu_B(q)\right]$$

Additionally, $\mu_{Be\ A}$ is defined as the linguistic variable B for surrounding A in the membership function, as indicated in the image (3).

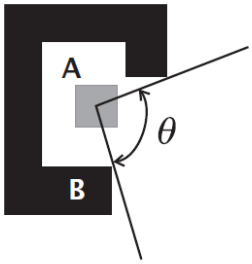

Figure-3: Calculation of fuzzy surroundedness (Tizhoosh, 1997b; Wang et al., 1997)

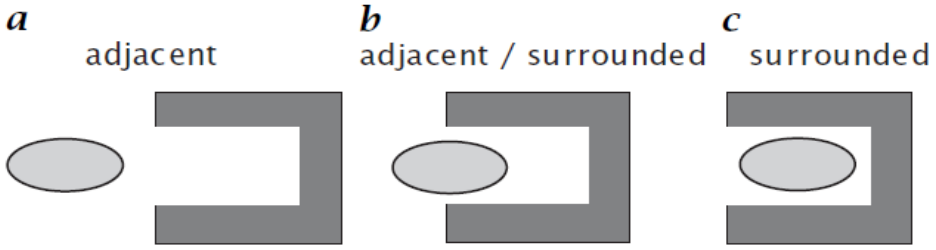

Figure-4: Relationship between adjacency and surroundedness (Tizhoosh, 1997b; Wang et al., 1997).

F. **Fuzzy adjacency:** In crisp sets, adjacency is the length of the common border of two disjoint sets.
Let μ_1 and μ_2 be the disjoint constant fuzzy sets of image G. For each region of image G_i, either μ_1 =0 or $\mu_2 = 0$

$A(i,j,k)$ be the k^{th} arc along which G_i and G_j meet, then

$$\text{adjacency}(\mu_1,\mu_2) = \sum_{i,j,k;i\neq j} \mu_1(i)\mu_2(j)\|A(i,j,k)\| \qquad (1)$$

Where, $\|A(i,j,k)\|$ is the length of the k^{th} arc

This definition may not be true for all the situations. If the difference between membership values is same, then

$$\text{adjacency}(\mu_1,\mu_2) = \sum_{i,j,k} \frac{\|A(i,j,k)\|}{1+\|\mu_1(i)\mu_2(j)\|} \qquad (2)$$

Let S_1 and S_2 be the two segments of an image G. Let $B(S_1)$ be the set of border pixels of S_1 and p an arbitrary member of B, then the degree of adjacency with respect to eq (1) is given as:

$$\text{degree of adjacency}(\mu_1,\mu_2) = \sum_{p\in B(S_1)} \frac{1}{1+d(p)}$$

Where, $d(p)$ is the shortest distance of pixel p from the border of segment S_2

The degree of adjacency with respect to eq (2) is given as:

$$\text{degree of adjacency}(\mu_1,\mu_2) = \sum_{\substack{p\in B(S_1)\\ q\in B(S_2)}} \frac{1}{1+\|\mu_1(i)\mu_2(j)\|}\cdot\frac{1}{1+d(p)}$$

Figure 4 shows the relationship between adjacency and surrounded-ness.

Depending upon the situations, one or both of the concepts could be considered. (Rosenfeld, 1979; Rosenfeld and Klette, 1985b; Pal and Ghosh, 1992)

1.4 Fuzzy image processing systems

Fuzzy image processing structure as is shown in figure 5 revels the three stages i.e. Fuzzification, Fuzzy Inference and the Defuzzification (if necessary). Figure 6 shows the various types of fuzzification of the image.

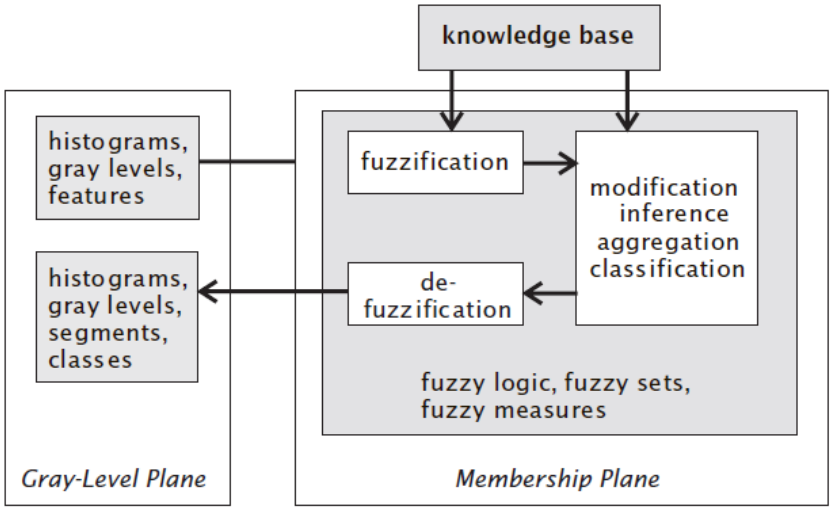

Figure-5: General structure of fuzzy image processing systems (Tizhoosh, 1997)

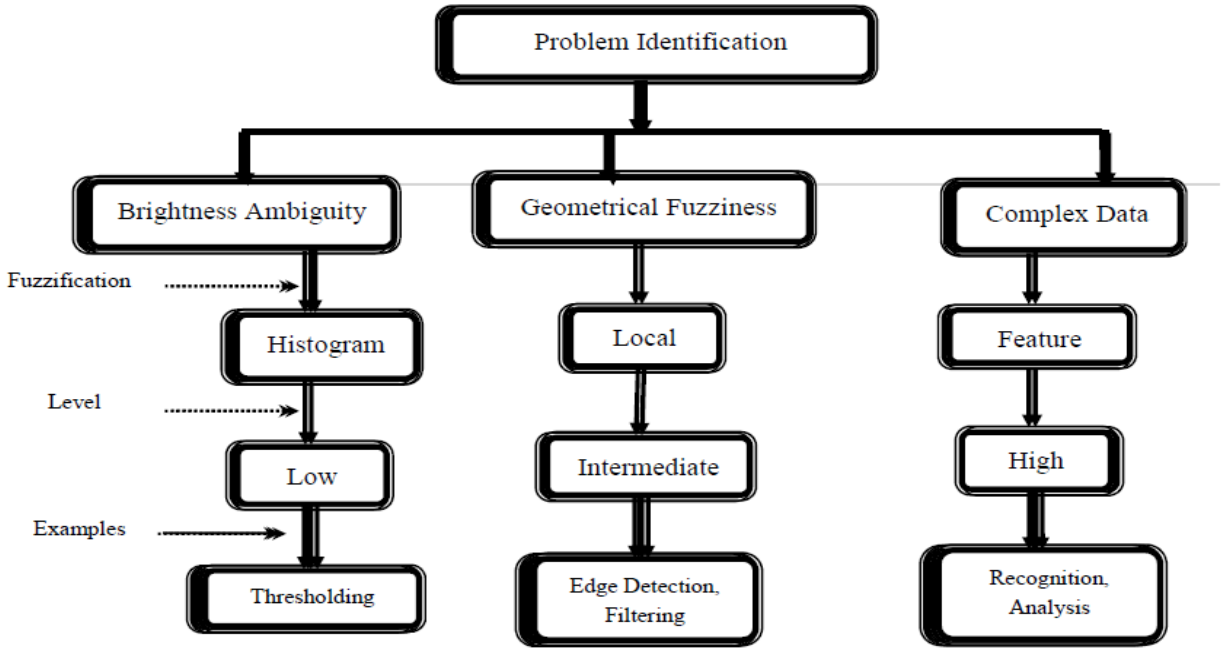

Figure-6: Various types of Fuzzification of the image (Tizhoosh, 1997)

1.5 Components of fuzzy image processing

According to (Tizhoosh, 1997), fuzzy image processing is a nonlinear reasoning based system consisting of components defined as:

A. **Fuzzy geometry:** The literature on image processing using fuzzy system reported the various versions of fuzzy applications based on area, perimeter, and diameter. (Rosenfeld, 1979, 1984a, 1984b; Rosenfeld and Haber, 1985; Rosenfeld and Klette,

1985; Pal and Ghosh, 1990, 1992) During the segmentation of the image, geometrical fuzziness arises and can be taken very well, if image or its segments are described in fuzzy sets. (Bhandari et al., 1992a, 1992b) Figure 7 below shows the feature extraction process using image segmentation by fuzzy topology.

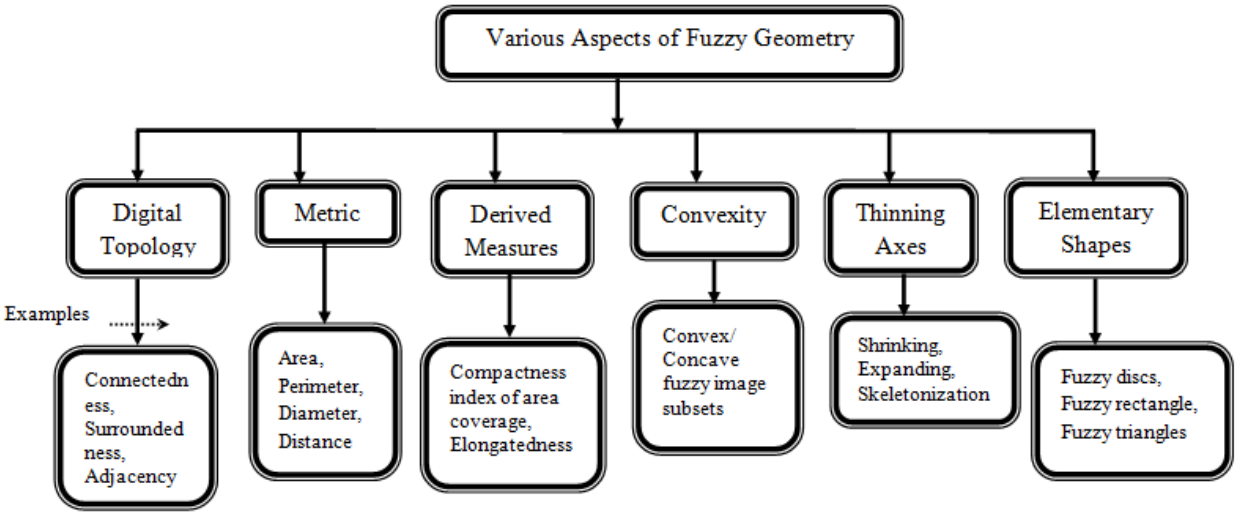

Figure-7: Various Aspects of Fuzzy Geometry (Tizhoosh, 1997

B. Fuzzy compactness: Let G be an image with size $m \times n$ with one object having membership value $\mu_{i,j}$, then

$$area(\mu) = \sum_{i=0}^{m} \sum_{j=0}^{n} \mu_{i,j}$$

$$perimeter(\mu) = \sum_{i=1}^{m} \sum_{j=1}^{n-1} \left\| \mu_{i,j} - \mu_{i,j+1} \right\| + \sum_{i=1}^{m-1} \sum_{j=1}^{n} \left\| \mu_{i,j} - \mu_{i+1,j} \right\|$$

$$compactness(\mu) = \frac{area(\mu)}{[perimeter(\mu)]^2}$$

In Classical set theory, it is maximum for a circle, whereas, in fuzzy sets, it is always more in the corresponding case. Many fuzzy techniques have been developed for the segmentation of image that minimizes the compactness. (Rosenfeld, 1984)

C. Index of Area Coverage (IOAC): The index of area coverage of a fuzzy image subset μ is given as:

$$IOAC(\mu) = \frac{area(\mu)}{length(\mu).breadth(\mu)}$$

Where, $length(\mu) = \max_i \left\{ \sum_j \mu_{i,j} \right\}$ and $breadth(\mu) = \max_j \left\{ \sum_i \mu_{i,j} \right\}$

Both the definitions of fuzzy compactness and (IOAC) are similar to each other and in many cases, there exist a relationship between them. (Pal and Ghosh, 1990,1992)

D. Fuzzy Elongatedness: This is a feature in fuzzy sets and used for the calculation of geometrical features such as, thresholding shown in figure 8.

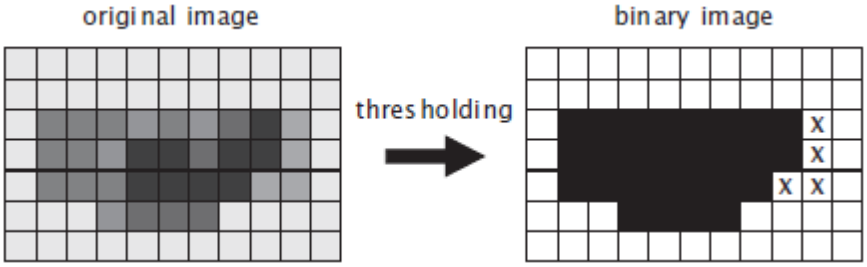

Figure-8: Calculation of Fuzzy Elongatedness (Rosenfeld, 1979)

It recognizes a certain class of objects and is defined as:

$$elongatedness(\mu) = \frac{area(\mu)}{[thickness(\mu)]^2}$$

$$fuzzy\ elongatedness(\mu) = \max_{\delta>0} \left[\frac{area(\mu - \mu_{-\delta})}{(2\delta)^2} \right]$$

Where, μ_δ is the result of a shrinking operation in a given distance δ. (Rosenfeld, 1979)

E. Index of Fuzziness: For a crisp set A, $A \cap \overline{A} = \varnothing$ but this condition will not holds for two fuzzy sets. A fuzzy set is, the more it intersects with its complement. The index of fuzziness is defined as:

Let μ_A be the membership function of fuzzy set A defined over an image G with size $m \times n$, then

Linear Index of Fuzziness

$$\gamma_1(G) = \frac{2}{mn} \sum_{i,j} \min\left(\mu_{ij}, 1 - \mu_{ij}\right)$$

$$\gamma_2(G) = \frac{2}{\sqrt{mn}} \left[\left(\sum_{i,j} \min\left(\mu_{ij}, 1-\mu_{ij}\right) \right)^2 \right]^{\frac{1}{2}}$$

Where, $\gamma_1(G)$ and $\gamma_2(G)$ be the linear and quadratic index of fuzziness respectively.

For crisp sets, both $\gamma_1(G)$ and $\gamma_2(G)$ equal to zero.

For fuzzy sets, both $\gamma_1(G)$ and $\gamma_2(G)$ reach the peak value of 1.

F. Fuzzy entropy: Entropy is the information theoretic measure that quantifies the information content of an image. Fuzzy entropy quantifies the uncertainty of the image content. De Luca[1972] proposed the logarithmic fuzzy entropy as:

$$H_{\log}(G) = \frac{1}{mn\ln(2)} \sum_{i,j} S_n(\mu_{ij})$$

Where, $S_n(\mu_{ij}) = -\mu_{ij} \cdot \ln(\mu_{ij}) - (1-\mu_{ij}) \cdot \ln(1-\mu_{ij})$

The exponential fuzzy entropy as:

$$H_{\exp}(G) = \frac{1}{mn(\sqrt{e}-1)} \left\{ \sum_{i,j} \mu_{ij} \cdot \exp(1-\mu_{ij}) - (1-\mu_{ij}) \cdot \exp(\mu_{ij}) - 1 \right\}$$

The fuzzy entropy measures uncertainty ranging from 0 to 1. (Pal and Pal, 1991)

G. Fuzzy correlation: To quantify the correlation between the two fuzzy features (brightness, edginess, texturedness, etc.) within the same image or same feature in two different images. The representation of the correlation as below:

$$K(\mu_1, \mu_2) = 1 - \frac{4}{\Delta_1 + \Delta_2} \sum_{i,j} (\mu_{1,ij} - \mu_{2,ij})^2$$

Where $\Delta_1 = \sum_{i,j} (2\mu_{1,ij} - 1)^2$ and $\Delta_1 = \sum_{i,j} (2\mu_{2,ij} - 1)^2$

If $\Delta_1 = \Delta_2 = 1$, K is set to unity. (Pal, 1992a)

H. Rule-based systems: Various researches were published and reported the theories based on fuzzy concepts used for image processing. (Zadeh, 1975a). Fuzzy set theory works well on rule-based systems without any analytical model and have the potential to deal with uncertain knowledge with expert knowledge. Rule based systems

comprises the tasks such as a). fuzzification; b). fuzzy-inference; and c). the defuzzification. It is the inference engine that constitutes rule-based systems and is the brain of fuzzy technique that establishes the relationship between input fuzzy sets and output fuzzy sets to modify membership functions according to the rule. The use of various fuzzy inference rules in image processing is the mostly used system. (Miyajima, 1992; Bezdek et al., 1996)

I. Fuzzy morphology: In general, the concept of fuzzy-morphology refers to generalizing the classical-morphology to the fuzzy sets. (Bloch and Maitre, 1993) Mathematically, the fuzzy-morphology is represented as below:

Let us assume that image is represented as fuzzy membership function μ with pixel size *'mXn'*, the membership function at any pixel is a fuzzy structuring element *'v'* is *'v_{ij}'*. Both the size of the morphological operation and its spatial area of influence are determined by this membership function. (Bloch and Maitre, 1995) Fuzzy dilation and erosion are the two basic morphological operations and determined as follows:

***Fuzzy erosion*:** $E_\nu(x) = \inf \max[\mu(y), (1-\nu(y-x))]; \forall\ x, y \in X$

$$E_\nu(x) = \inf[\mu(y) \cdot \nu(y-x) + 1 - \nu(y-x)]; \forall\ x, y \in X$$

(Bloch, 1996; De Baets, 1997)

Fuzzy dilation: Let $E_\nu(x) = \sup \min[\mu(y), \nu(y-x)]; \forall\ x, y \in X$

$E_\nu(x) = \sup[\mu(y) \cdot \nu(y-x)]; \forall\ x, y \in X$ (Bloch, 1996; De Baets, 1997)

J. Fuzzy Measure Theory: In image data, many inherent vague situations such as: Brightness, edginess, homogeneity and other can easily handled by Fuzzy sets, because the boundary of the classes are not crisp. The fuzzy set theory offers suitable framework to apply expert knowledge within complex processing tasks. In image processing, usually uncertainty arises in crisp relationships, like the problem of thresholding occurs, when extracting two classes of pixels belonging to object and background respectively and is due to ambiguity. (Wang and Klir, 1992) Such type of problems can be handled through fuzzy measures and fuzzy integrals which are the non-linear aggregation operators. These integrals are used for combining the various uncertain information's in one go. (Chi et al., 1996; Gader et al., 1996).

K. Fuzzy Measures: In the fuzzy measures, X represents the set of features (or images of different sources etc.), a fuzzy measure $f : 2^X \to [0,1]$ over the set X in a measurable space (X, K), where K is the power of X satisfies the following conditions:

Boundedness: $f(\varnothing) = 0$ and $f(X) = 1$

Monotony: $A, B \in K;\ A \subset B \ \Rightarrow\ f(A) \le f(B)$

Lower Continuity: $\{A\} \subset K,\ A_1 \subset A_2 \subset ....., \underset{n=1}{\overset{\infty}{\mathrm{U}}} A_n \in K \ \Rightarrow \lim_{n\to\infty} f(A_n) = f\left(\underset{n=1}{\overset{\infty}{\mathrm{U}}} A_n\right)$

Upper Continuity: $\{A\} \subset K,\ A_1 \supset A_2 \supset ....., \underset{n=1}{\overset{\infty}{\mathrm{I}}} A_n \in K \ \Rightarrow$

$$\lim_{n\to\infty} f(A_n) = f\left(\underset{n=1}{\overset{\infty}{\mathrm{I}}} A_n\right)$$

For the purpose of subjective estimation of each information source the set of functions are used known as fuzzy measures. Sugeno (1974) introduced the class of fuzzy measures that later known as λ- fuzzy measures. A fuzzy measure f_λ is a Sugeno measure in (X, K), if it satisfies the following rules:

1. A, B and $A \cup B \ \in K,\ A \cap B = \varnothing$
2. $f_\lambda(A \cup B) = f_\lambda(A) + f_\lambda(B) + \lambda f_\lambda(A) f_\lambda(B)$
3. $\lambda \in \left(-1/\sup f_\lambda(A), \infty\right) \cup \{0\}$

In image processing, the fuzzy measures deal with finite numbers of elements. The λ-rule can be formulated as:

$$f_\lambda\left(\underset{j=1}{\overset{n}{\mathrm{U}}} A_j\right) = \begin{Bmatrix} \sum_{j=1}^{n} f_\lambda(A_j), & if\ \lambda = 0 \\ \frac{1}{\lambda}\left[\prod_{j=1}^{n}\left(1 + \lambda f_\lambda(A_j)\right) - 1\right], & if\ \lambda \neq 0 \end{Bmatrix}$$

If the value of λ is known, sugano measure can be constructed completely.

Let $X = \{x_1, x_2, ..., x_n\}$ be the universe of discourse.

$$f_\lambda(X) = \frac{1}{\lambda}\left[\prod_{j=1}^{n}\left(1 + \lambda f_\lambda(\{x_j\})\right) - 1\right]$$

The value of λ can be calculated from the following equation:

$$1+\lambda f_\lambda(X)=\prod_{j=1}^{n}\left(1+\lambda f_\lambda(\{x_j\})\right)$$

For $f_\lambda(X)=1$, the polynomial expression is:

$$1+\lambda=\prod_{j=1}^{n}\left(1+\lambda\mu(\{x_j\})\right)$$

L. Fuzzy Integrals: The fuzzy integral of a function $g: X \to [0,1]$ over *'X'*, with respect to the fuzzy measure f is defined as:

$$\int g(x) \circ f = \sup_{a\in[0,1]}[\alpha \wedge f(F_\alpha)]\text{; Where, } F_\alpha=\{x \mid g(x)\geq\alpha\}$$

The properties of fuzzy integrals are:

1. $\int a \circ f = a,\ a\in[0,1]$
2. $\int g_1 \circ f \leq \int g_2 \circ f$, if $g_1 \leq g_2$
3. $\int_A g \circ f \leq \int_B g \circ f$, if $A \subset B$

These components can be used to develop new techniques/algorithms.

1.6 Application of fuzzy theory to image processing

Some of the applications of fuzzy image processing are:

- **Image enhancement:** In image processing, the prevention from the development of noise, blurring, geometrical distortions, illumination corrections etc. are the important concerns pertaining to extraction of information from the images. The incorporation of Fuzzy sets in image processing will help in providing the better understanding on image characteristics/functions such as: pixels, histograms, segments etc. and transforming them into membership planes easily. The proposed work will provide the algorithm that can enhance the information level and shield the images from the aforesaid causes.
- **Edge detection:** Edges are regarded as one of the key components of low-level image processing, which comes after processes like object recognition and motion analysis. It is a frequent source of failures in the current image processing methods. The fuzzy based techniques will be presented in this work to quantify the intuitive presence of the edges.
- **Image segmentation:** Another significant aspect and prerequisite for processing complicated images is the image segmentation. Understanding of the fuzzy theories

based picture segmentation and clustering process will be provided by the current work. This will aid in the analysis of fuzzy geometrical measures and fuzziness.

2.0 LITERATURE REVIEW

In day-to-day business activities, the large number of data is collected, analysed and interpreted for the effective and smooth working of an organization. Large volumes of scanned documents are processed automatically through optical character recognition (OCR), bank cheque reader, signature verifier etc. It is the toughest task to index, retrieve and organize the documents, and further classify them based on image analysis. (Ohlan, 2016) Even, the data available in tabular form, invoices, receipts etc. is also has the requisites to classify and organized as separate entities.

At the initial stage, the linear filtering process were introduced to remove the noise. Still, this filtering process was little-bit effective. The linear filters by convolution remove noise from the original image with a mask. This provides the blurred image if the value of standard deviation of the mask is higher. (Alan, 2006) Later, the Gaussian filters were used to remove grain noise from a photograph. (Rafael, 2002) In addition, the methods such as conserve smoothing, standard median filter (SMF) were also used to eliminate the noise from images. The former method (linear filtering) was designed to remove noise such as salt and pepper type, whereas, the later one (Gaussian filters) was good for removing the impulse noise. Still, both the filters were not capable to remove the additive noise. (Alan, 2006). Later on, another filter named Wiener filters were devised to remove the noise from the images. The Wiener filters was used to perform image smoothing and works well to remove Gaussian noise. This filter was not effective because of the larger amount of computational time as compared to other linear filters. Even, it was not suitable for the images that have more edges. The visual quality was the other challenge in using this filter. (Rafael, 2002; Kenneth, 2003) The wavelet-based methods for noise reduction were also utilized as they preserve image details but these methods were very complex and time consuming. (Hansen, 2000) Another development in the image processing was the introduction to conservative smoothing process that suppress noise with the help of filtering algorithm. (Kenneth, 2003) The conservative smoothing process was also not effective in removing Gaussian noise from an image. Even more non-linear filters were created to reduce noise from images, including weighted median, rank conditioned rank selection, and

relaxed median. Although these filters were still employed efficiently, the additive gaussian noise remained. (Rafael, 2002)

Later, 1970's, the fuzzy filters were developed to overcome the shortcomings of the linear filters used in image processing. The introduction to the fuzzy algorithms in the discipline of fuzzy image processing was gaining popularity after 1990's. (Pal, 1994) The fuzzy filters handle the vague and uncertain information in which each pixel in the image is represented by a membership function and different fuzzy rules have been applied to perform edge smoothing and preservation. (Van, 2001) For the development of fuzzy filters, the fuzzy set theories were used. The fuzzy set theory offers the variety of tools that represent human knowledge. Many fuzzy based filters have been developed for noise reduction but these filters are developed only for greyscale images.

Every edge detecting problem has three stages as: filtering, detection and tracing. (Law, 1996; Akbari; 2005) The algorithm was proposed that gather edge information and the technique is very useful in the detection of edge of images corrupted by noise. The fuzzy thresholding technique was also discussed in literature which helps in preserving the edges and other fine details of the images which results in elimination of impulse noise from an image. (Kenneth, 2003) The pool of regions for multiple image segmentations in which each region has been assigned with a probability of belongingness to an object class was developed. (Russell, 2006) In each image, the region with the highest probability was considered to be containing the object, which desires the need for multiple segmentations to get good object support. Later on, the various multi-scale segmentation methods were developed and used to identify the good object support. The use of mean and standard deviation of the greyvalues in the region with the entropy of the histogram was proposed. This will help in spatial structure modelling with the combination of relative weights of region information that is defined by the distance between region centers of mass. (Todorovic and Ahuja, 2006) For blurry images, the fast and reliable method, which is milti-level fuzzy edge detection techniques that first enhances the image contrast and then extract the edges from the enhanced images was also developed. (Wu et al, 2007)

The process to measure the fuzzy inference in image processing is also reported. This reveals that the robustness to contrast and lighting variations is considered to avoid in obtaining double edges. (Rosenfeld and Klette, 1985) Further, image thresholding is used for image segmentation. (Liao et al., 2001) Based on the probability partition, the fuzzy partition and

entropy theory was developed based on three-level thresholding for the image segmentation work. This segmentation further helps in finding the optimal combination of all the fuzzy parameters. (Tao et al., 2003; Zhao and Xu, 2016)

The literature also reported the colour image segmentation using fuzzy theory that automatically classify colours and image segmentation with minimum error rate. (Sertel et al., 2008) This technique is used with particle swam optimization technique to find membership functions and fuzzy rules. Further, the method for filtering colour images having Gaussian noise was proposed. The method provides promising results as compared to the existing filtering techniques. (Schulte et al., 2007) On the same tune, the modified fuzzy approach was proposed that used a Gaussian combination membership function against the fuzzy filter. (Madhu; 2008) Both these techniques were better than the classical filtering as well as fuzzy filtering techniques. Another algorithm was proposed considering the fuzzy clusters and active contours that addressed the issues of prostrate tissue. The algorithm counts the number of nuclei from spatial distribution of nuclei but the algorithm proved to be difficult in measuring the degree of consistency. This method was reliable to address the common problems of medical diagnosis. (Hafiane et al., 2008) The modified threshold selection method (initially proposed by Otsu in 1979) reveals that histogram thresh-holding technique is the main anchor in the image processing. (Huang and Wang, 2009) Still, there were certain drawbacks such as more time require in computation and even the pixel loses at the border while removing the additive noise from the image. (Salamat et al., 2021).

3.0 DESCRIPTION OF THE BROAD AREA

In the age of information, the data is available in digital form and mostly in image form. Therefore, the development of new database management techniques has become more popular among the community of researchers and there is a dire need to develop intelligent systems that deals with data effectively and efficiently. The systems have the capability to transform huge amount of scanned information to digital images is the need of the day. Not only this, the availability of videos is growing at an exponential pace, which opens doors for the researchers to do work in the development of effective video data management system. In this work, several algorithms have been proposed that manages image as well as video processing.

4.0 OBJECTIVES

The main objective of the proposed work is to develop new information theoretic measures for image processing. The objective are as follows:

- To design a mathematical model & define algorithm for the same.
- To propose the algorithms for the enhancement and segmentation of images using information theoretic measures.
- To investigate the applications of generalized information theoretic entropy measures to analyze images.
- To analyze the behavior of various information-theoretic measures to extract most of the key features of the images.
- To address the weaknesses in the existing image segmentation methods and propose features that represent better regions.

5.0 METHODOLOGY

The present era is well-known for digitization. A lot of data to take the decisions for industrial decision-making is based on the data extracted by the images through processing. A small error in extraction will cause the decision so it's become prominent to extract the data very carefully. Earlier 1960's, the images were scanned and information extracted through linear mathematical models. Though, the model developed at that time were very popular, still those models were having the limitations. This will further impact to the data and the decision. The presents study seeks to identify the issues pertaining to the image processing and eliminating those to extract the précised information from an image. For this purpose, literature related to the fuzzy image processing will be reviewed and classified to reveal the various fuzzy models used for image processing. Based on the literature, the present work also seeks to propose the mathematical model for theoretic measure of the images which would be much better than the models already in use.

6.0 PROPOSED/EXPECTED OUTCOMES OF THE RESEARCH

The proposed outcome of the work is as follows:

- Development of Algorithms that are used for the enhancement and segmentation of images.
- Analysis of images using information theoretic entropy measures.
- Propose features that address weakness in the existing image segmentation methods for the representation of better regions.

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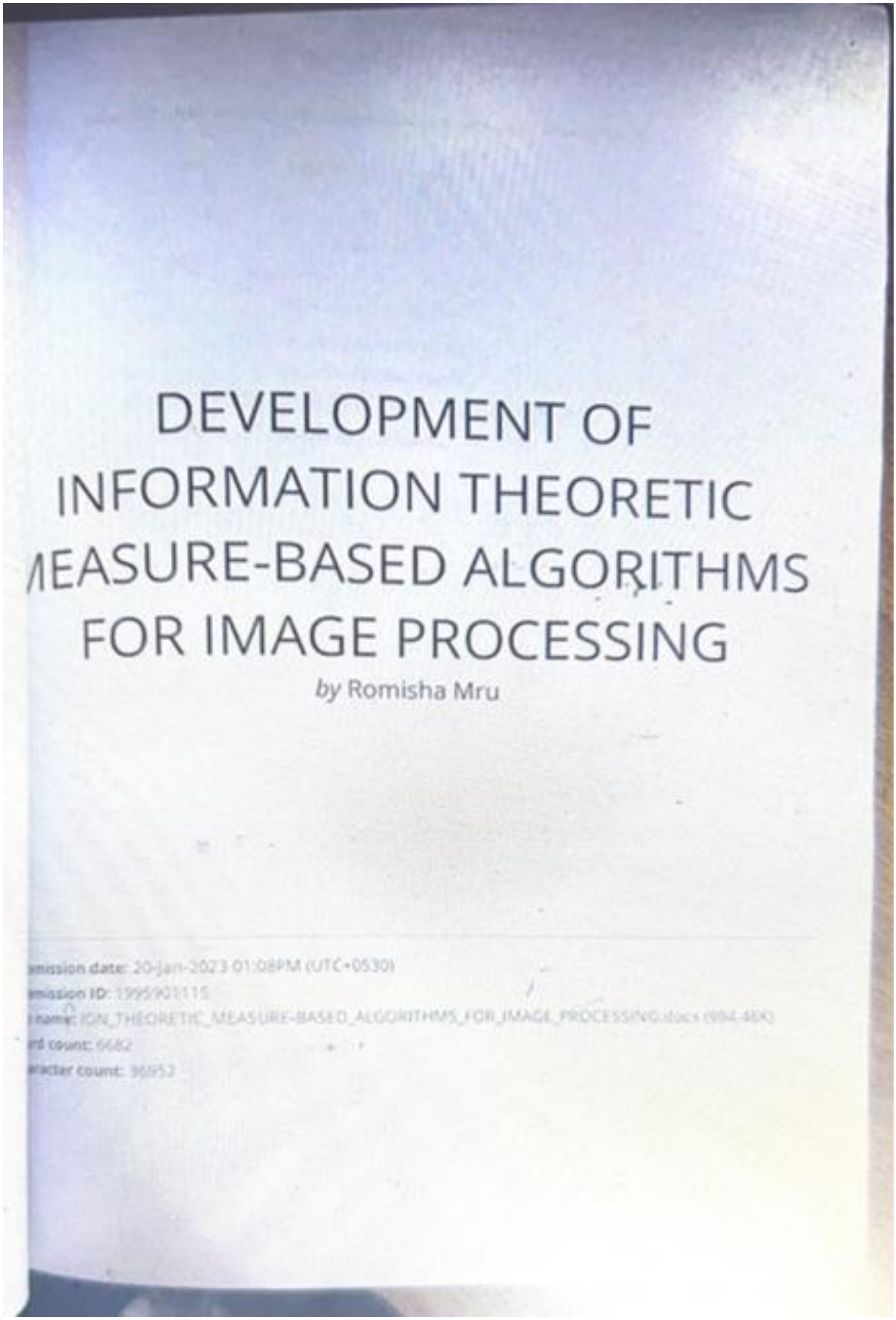
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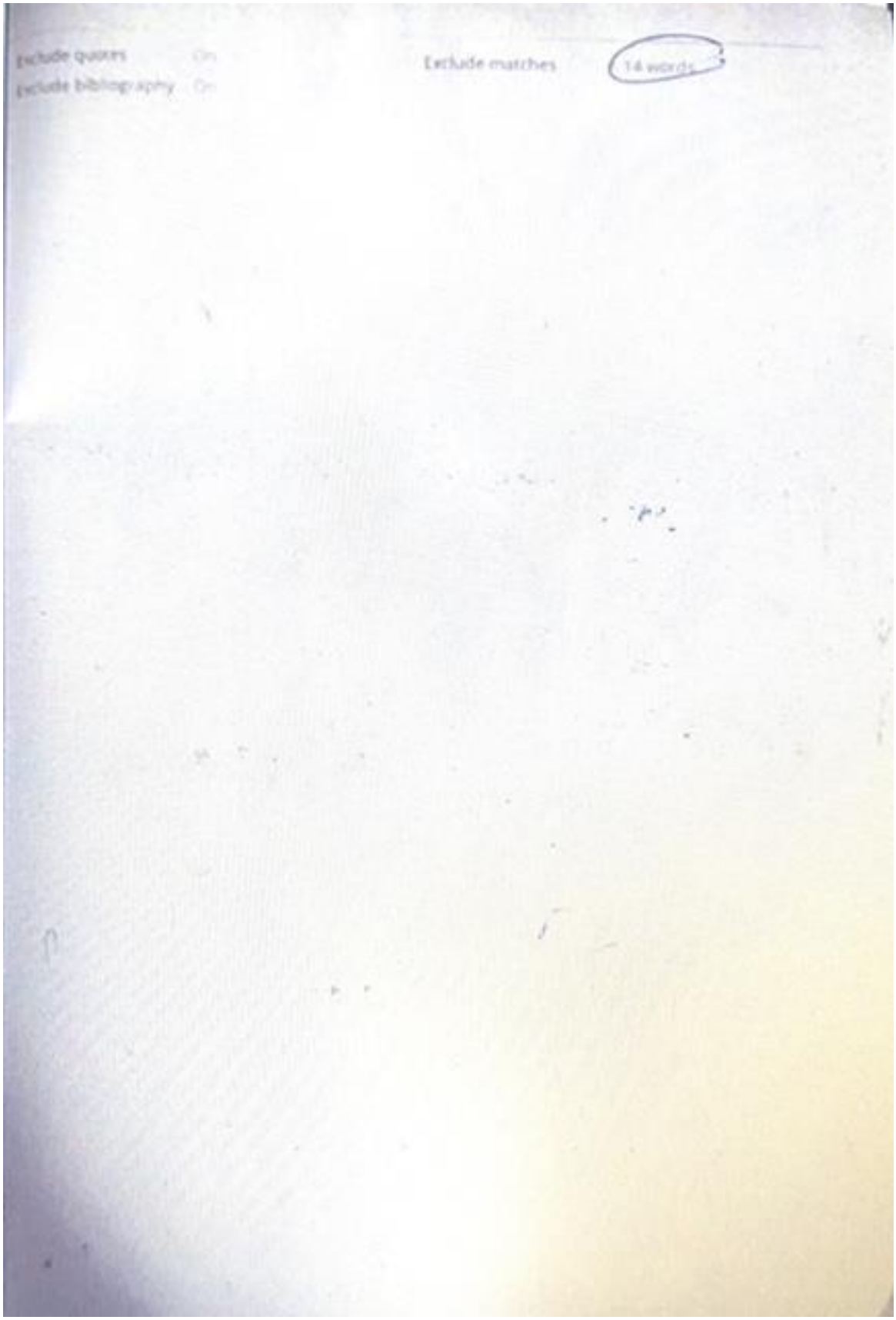
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